

GOES Type III Loop Heat Pipe Life Test Results
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Laura Ottenstein
NASA/Goddard Space Flight Center
Greenbelt, MD
Laura.Ottenstein-1@nasa.gov
Phone: 301-286-4141

The GOES Type III Loop Heat Pipe (LHP) was built as a life test unit for the loop heat pipes on the GOES N-Q series satellites. This propylene LHP was built by Dynatherm Corporation in 2000 and tested continuously for approximately 14 months. It was then put into storage for 3 years. Following the storage period, the LHP was tested at Swales Aerospace to verify that the loop performance hadn't changed. Most test results were consistent with earlier results. At the conclusion of testing at Swales, the LHP was transferred to NASA/GSFC for continued periodic testing. The LHP has been set up for testing in the Thermal Lab at GSFC since 2006. A group of tests consisting of start-ups, power cycles, and a heat transport limit test have been performed every six to nine months since March 2006. Tests results have shown no change in the loop performance over the five years of testing. This presentation will discuss the test hardware, test set-up, and tests performed. Test results to be presented include sample plots from individual tests, along with conductance measurements for all tests performed.

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- Conclusions

BACKGROUND

Background

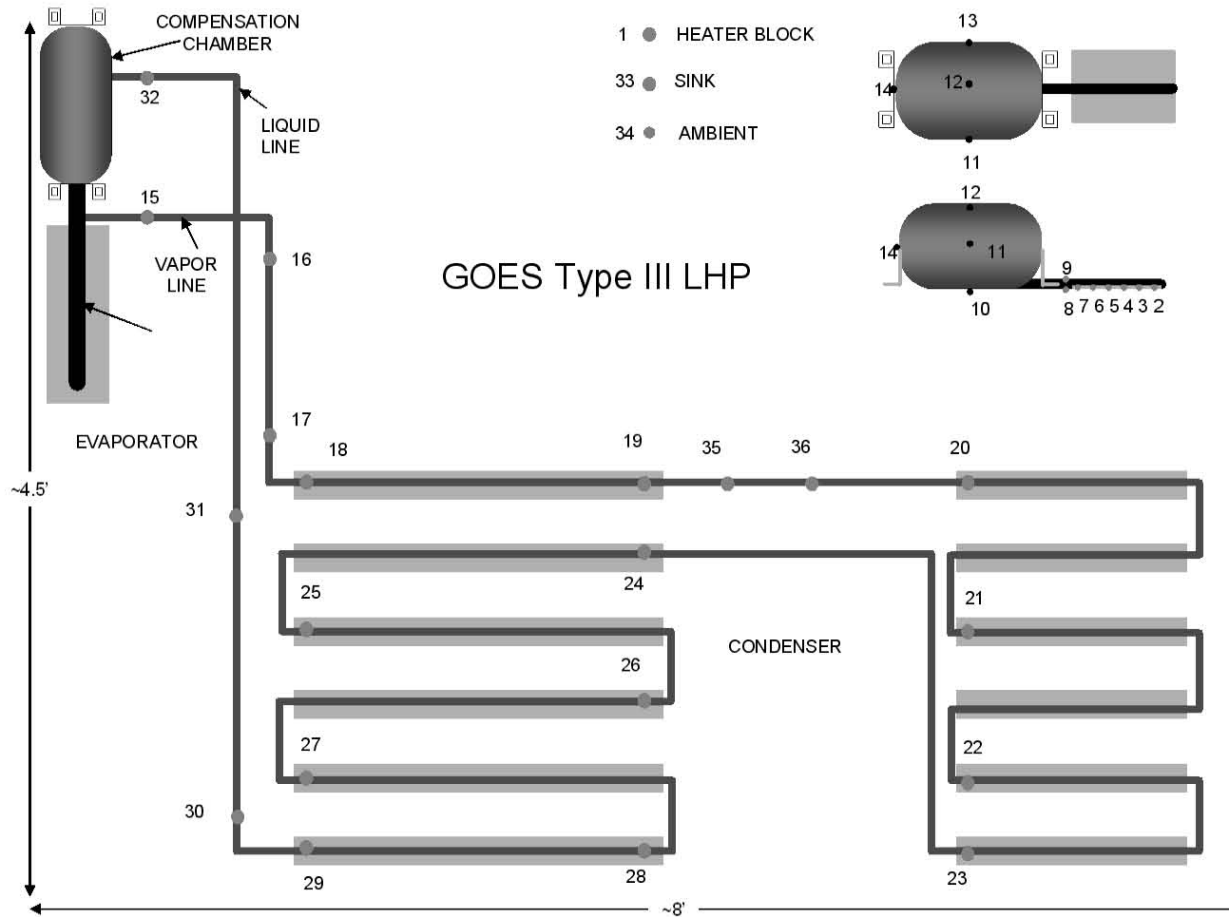
- GOES Type III Loop Heat Pipe (LHP) was built as a Life Test Unit for the LHPs on the GOES N-Q series satellites
- Built by Dynatherm Corporation in 2000 for Boeing and later transferred to Swales Aerospace
- Operated continuously at Dynatherm for approximately 14 months, then put into storage at Boeing until 2004
- Tested again at Swales in 2004
 - Unexpected performance during cold sink identification test led to additional tests and additional unexpected performance
 - At conclusion of testing it was determined that performance anomaly was most likely due to test set-up or gravity effects and not likely to occur on orbit
- LHP was transferred to GSFC in 2006 for continued periodic testing (in ambient)
- LHP has been tested every six to nine months from March 2006 through January 2011

TEST ARTICLE AND TEST SET-UP

LHP Description

- LHP contains a single 2.54 cm (1") diameter evaporator and a single condenser
- Condenser has flanges in cooling locations, but no mounting holes
- Flexible sections in liquid and vapor lines, although not significantly flexed in current test set-up
- Charged with propylene

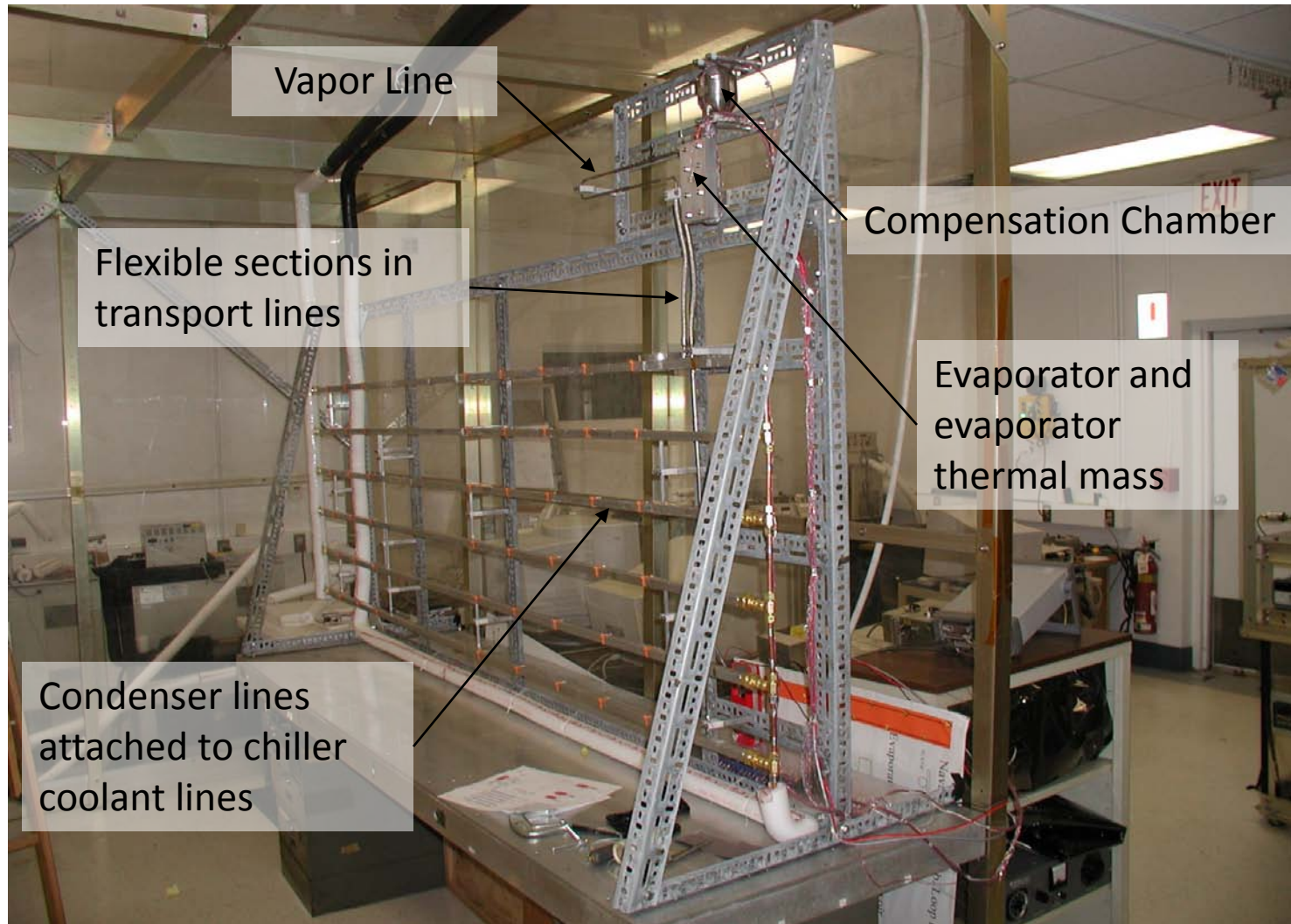
Loop Schematic with Thermocouple Locations



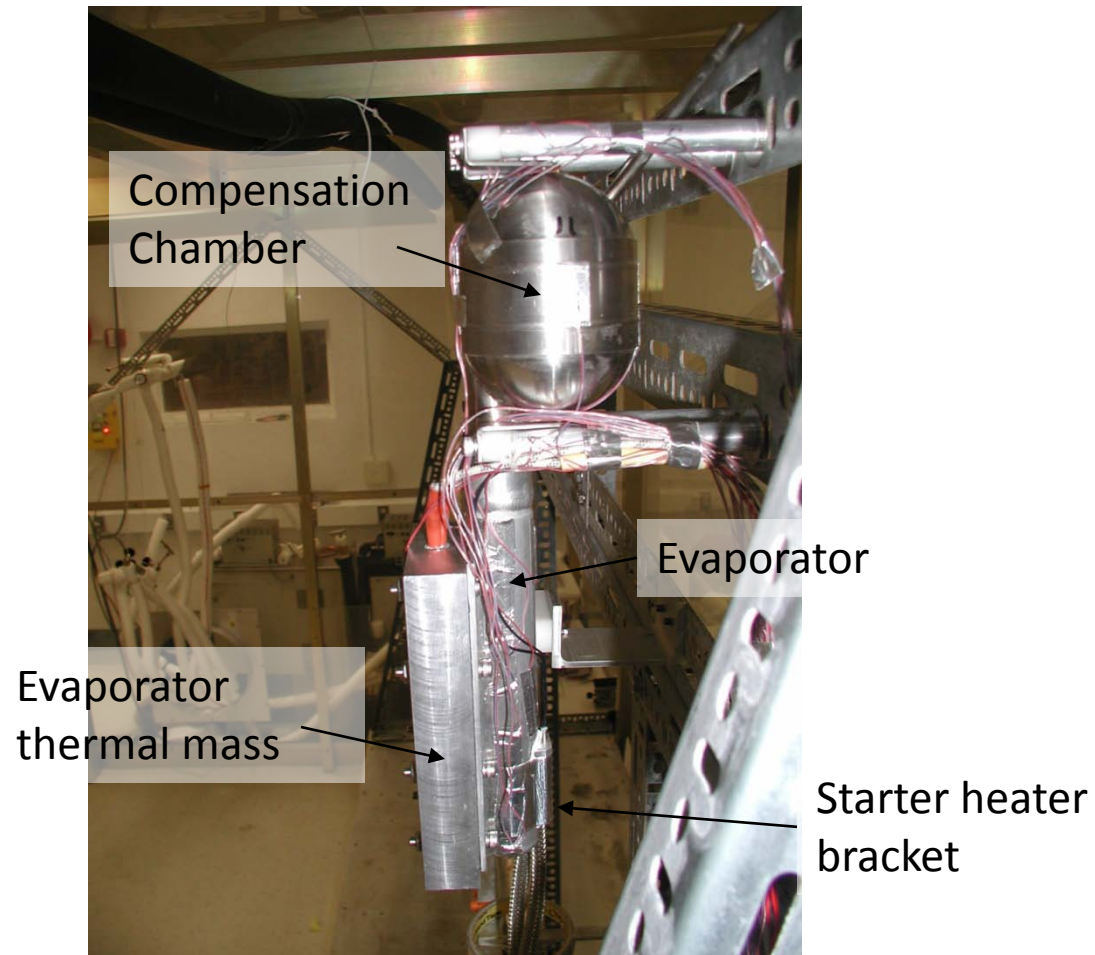
Test Set-Up

- Loop heat pipe held vertically by a support frame
- Six parallel cooling lines plumbed to chiller (reverse return). Square tubing is connected with thermal grease and tie wraps to condenser flanges
- Approximately 36 Type T thermocouples installed on LHP using aluminum tape
- Aluminum heater block (825 grams) and starter heater saddle mounted to evaporator
 - Grafoil used between heater block and evaporator mounting flange
 - Cartridge heater capable of up to 500 W installed in heater block
 - Cartridge heater capable of up to 50 W installed in starter heater saddle
- Thermocouple data collected using a Agilent Data Acquisition Unit and displayed on PC using LabView
- Heaters controlled manually using variacs
- Power readings displayed on Valhalla Scientific Digital Power Analyzers and recorded manually
 - over-temperature controllers in heater circuits for safety

LHP in Test Frame



Evaporator/Compensation Chamber



Test Set-Up - Insulation

- Condenser/chiller tube assemblies are individually wrapped with aluminum foil and then wrapped with an overlapping layer of Spiral-On II thermal insulating tape
- Chiller coolant lines and transport lines individually insulated with polymer insulation foam
- Evaporator and Compensation Chamber assemblies insulated with Nomex; Nomex wrapped with Spiral-On II thermal insulating tape to limit condensation on Nomex

LHP with Insulation



TESTS PERFORMED

Test Rounds

- Each test round (every 6 – 9 months) consisted of approximately 5 days of testing:
 - Start-up/Heat Transport Limit Test (one test)
 - Start-up/Power Cycle with condenser preconditioning (one test)
 - Start-up/Power Cycle without condenser preconditioning (repeated for three tests total)
- Test order was not consistent between rounds
- Loop was left idle (off), but undisturbed between test rounds

Start-up/Power Cycle

with condenser pre-conditioning

- Chiller turned on and set to $-40\text{ }^{\circ}\text{C}$ and condenser temperatures allowed to stabilize
- 10 W to starter heater, 50 W to thermal mass heater
- Thirty minutes after loop start, thermal mass power increased to 150 W and allowed to stabilize (10 W left on starter heater)
- Thermal mass power decreased to 50 W and allowed to stabilize (10 W left on starter heater)
- All power off, chiller off

Start-up/Power Cycle

without condenser pre-conditioning

- Chiller turned on and set to $-40\text{ }^{\circ}\text{C}$, 10 W to starter heater, 50 W to thermal mass heater, all simultaneously
- Thirty minutes after loop start, thermal mass power increased to 150 W and allowed to stabilize (10 W left on starter heater)
- Thermal mass power decreased to 50 W and allowed to stabilize (10 W left on starter heater)
- All power off, chiller off

Start-up/Transport Limit Test

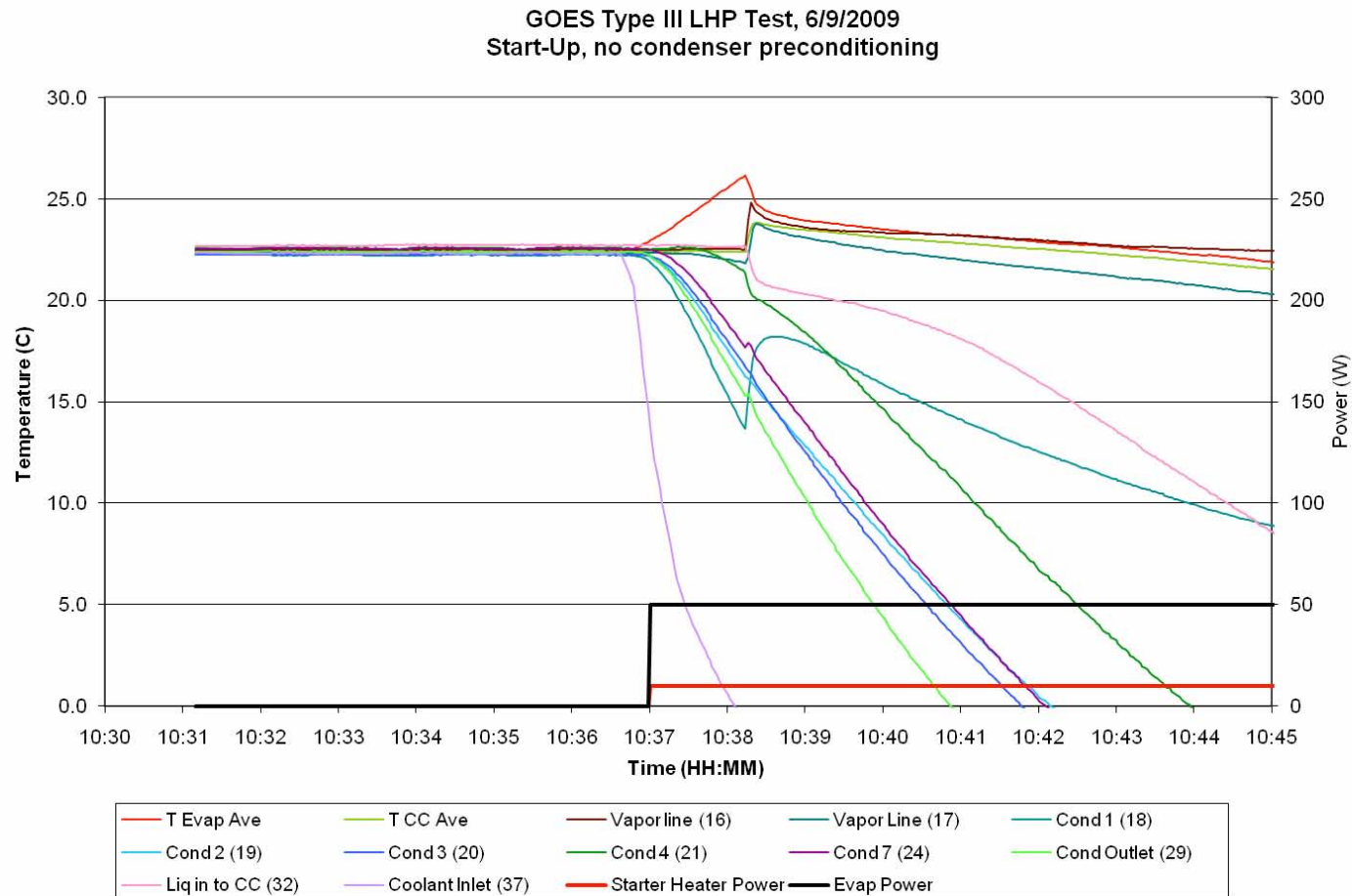
- Chiller turned on and set to $-40\text{ }^{\circ}\text{C}$ and condenser temperatures allowed to stabilize
- 10 W to starter heater, 50 W to thermal mass heater
- Thirty minutes after loop start, thermal mass power increased to 100 W and allowed to stabilize (10 W left on starter heater throughout entire test)
- Thermal mass power increased in 50 W steps until 200 W reached, then in 25 W steps. System allowed to stabilize after each power change
- When loop shows clear signs of dryout, power decreased to 50 W and allowed to stabilize
- All power off, chiller off

TEST RESULTS

Results: Start-Up Tests

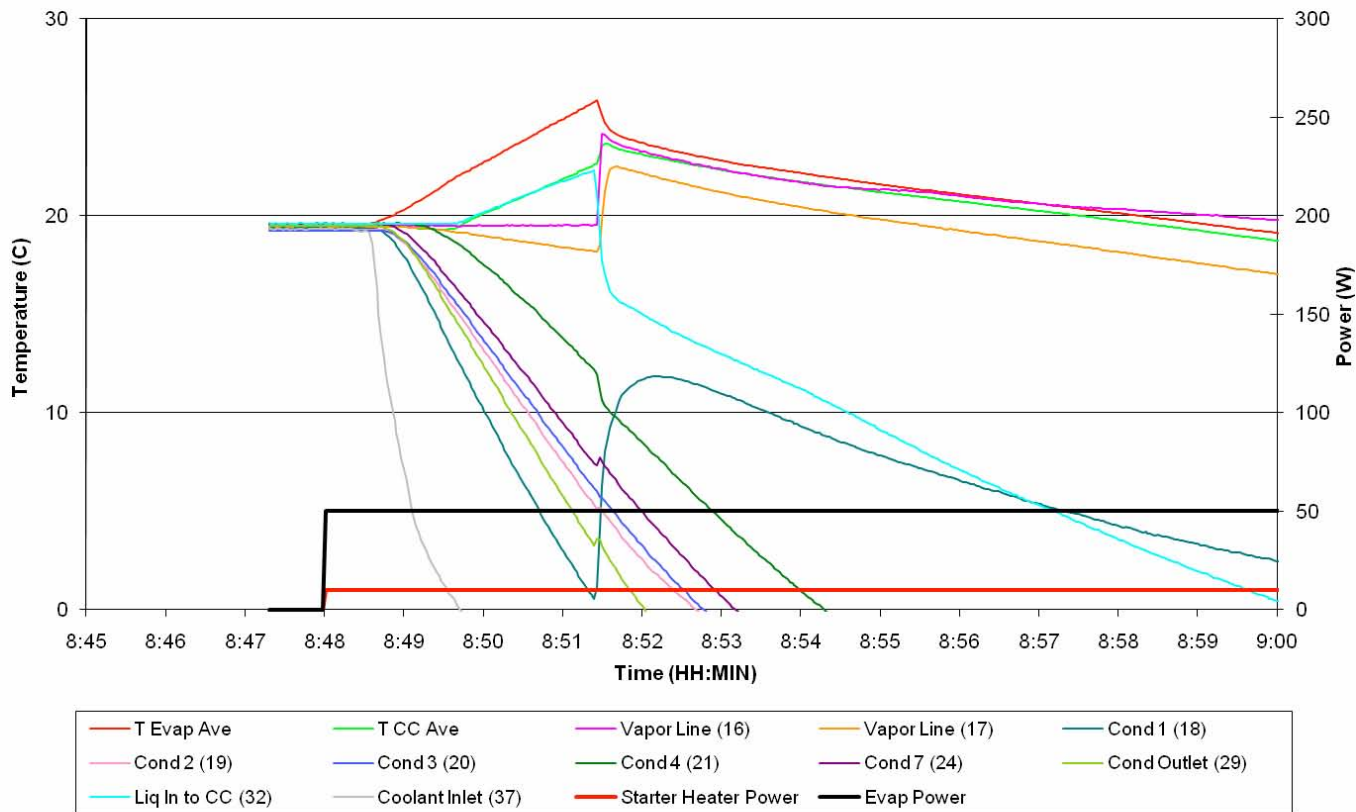
- In all tests, LHP started within five minutes of power application
- CC temperature generally constant before start-up
 - In a few tests, the CC temperature increased when power was applied to the evaporator; these tests had the longer start-up times
- Evaporator start-up superheat ranged from 3.5 °C to 7.8 °C, with an average value of 5.7

Typical Start-Up



Start-up with CC Temperature Increase

GOES Type III LHP Test - 4/3/2006
Start-Up, no condenser preconditioning

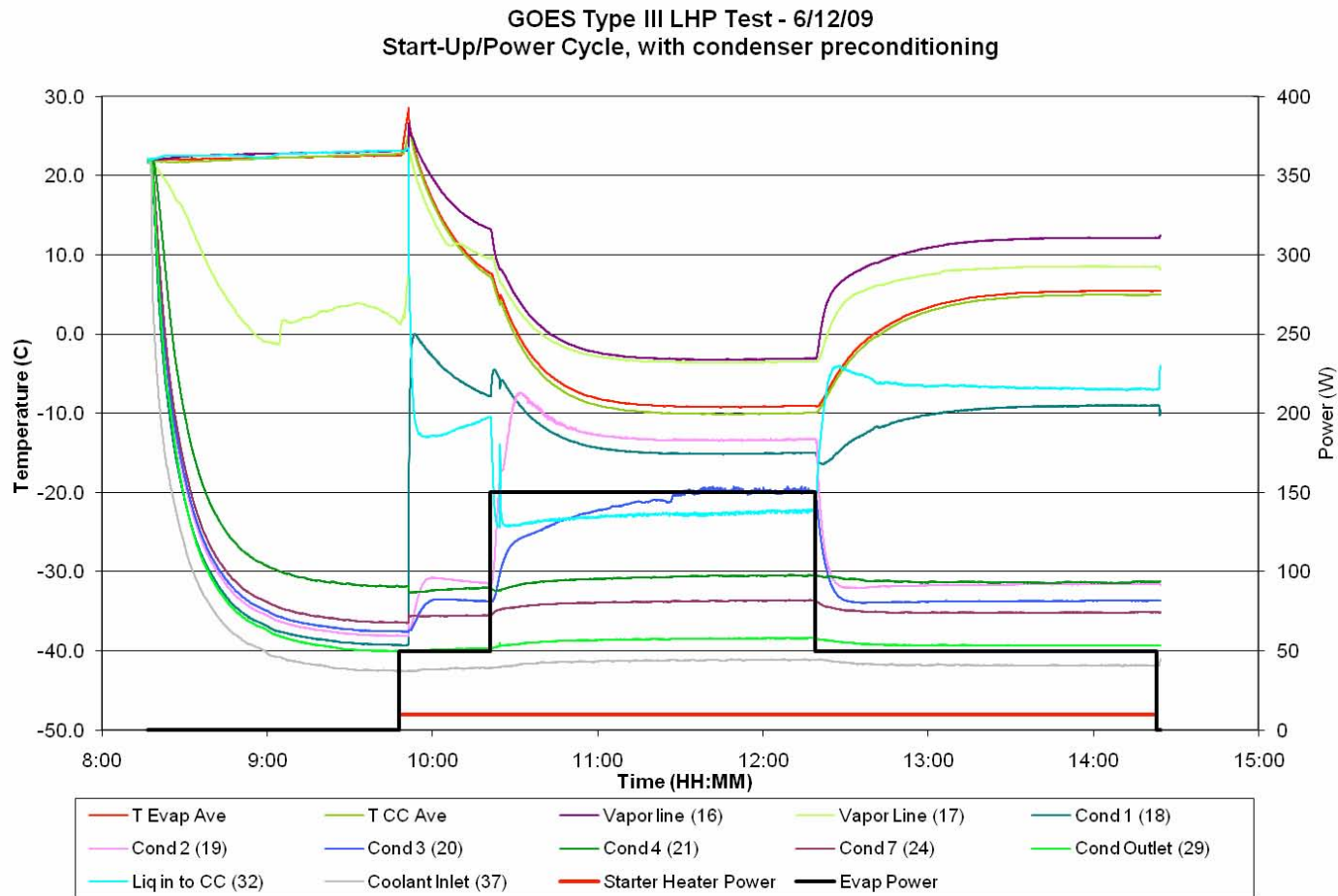


Results: Power Cycles

with condenser preconditioning

- All tests completed successfully
- Similar conductances in all tests (shown later in presentation)
- Frequent temperature “blip” in CC inlet temperature believed to be caused by gravity effects as condenser opens

Start-Up/Power Cycle with condenser preconditioning

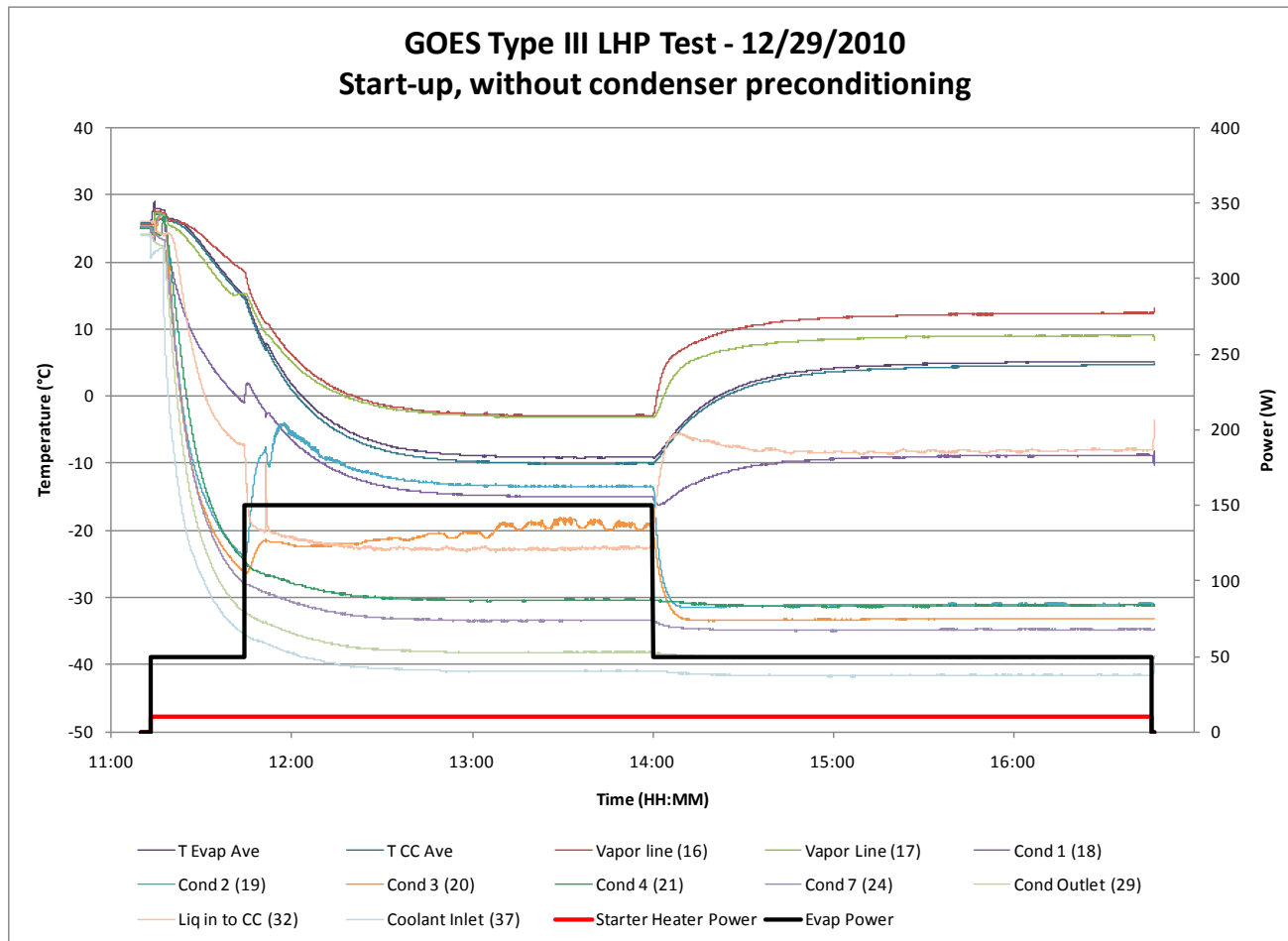


Results: Power Cycles

without condenser preconditioning

- All tests completed successfully
- Similar conductances in all tests (shown later in presentation)
- Similar results to tests with condenser preconditioning
 - Powerful chiller means that condenser cools quickly when chiller is started

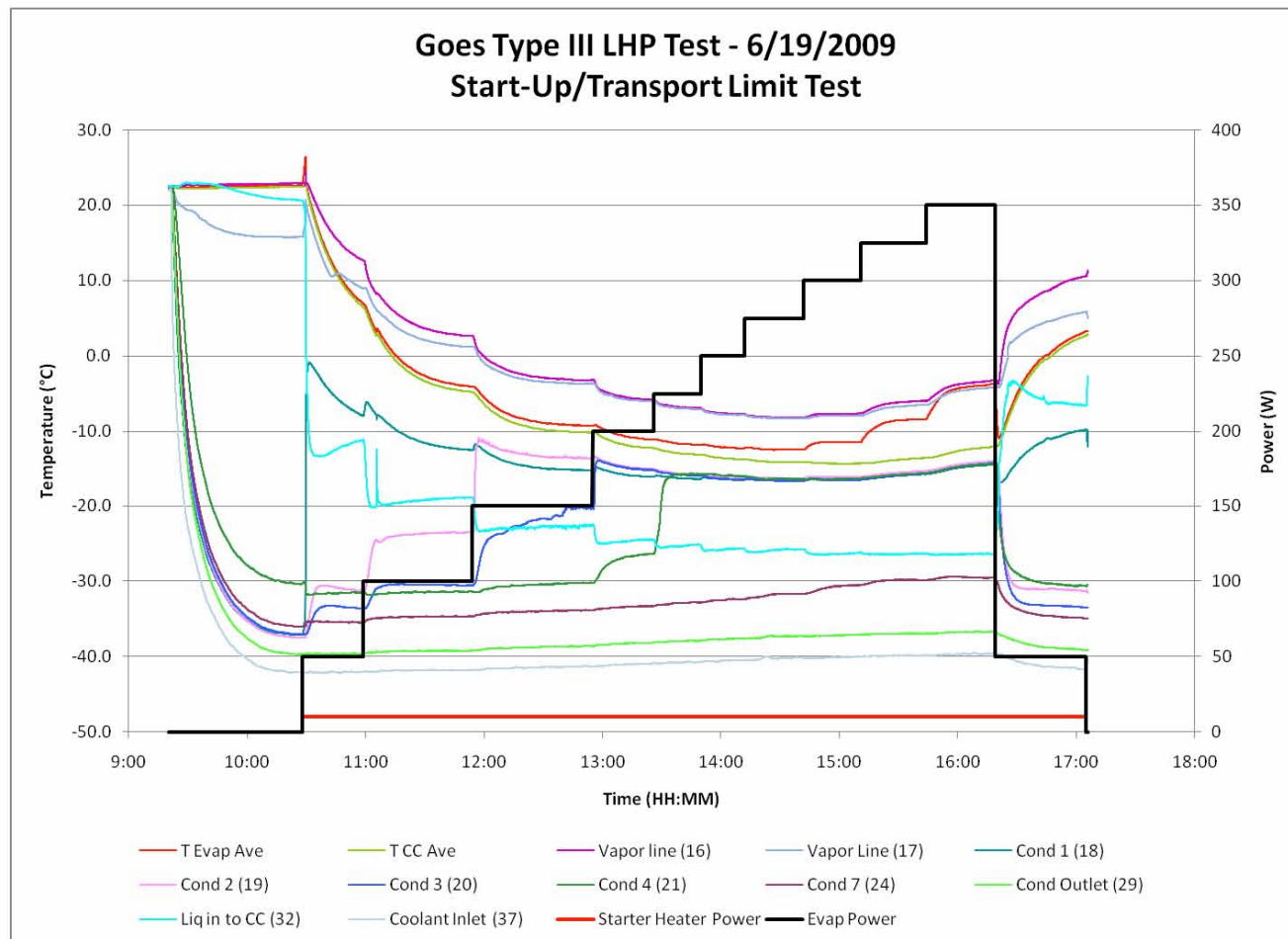
Start-up/Power Cycle without condenser preconditioning



Results: Heat Transport Limit Test

- Maximum power during test ranged from 310 W to 360 W
 - Dryout difficult to discern during testing, mainly seen as increasing temperature difference between evaporator and CC
 - Conductance calculations done after the tests indicate that loop performance always starts to degrade above 285 W
- Loop always recovered at turn-down power of 50 W
- No significant change in performance over time

Start-up/Heat Transport Limit Test



Conductance Calculations

Three conductance values were calculated for each test

Total conductance is defined as:

$$C_T = \frac{Q}{T_{\text{evap,ave}} - T_{\text{cond,ave}}}$$

where Q is the total power into the evaporator, $T_{\text{evap,ave}}$ is the average evaporator temperature (TCs 2-9), and $T_{\text{cond,ave}}$ is the average of TCs 18 and 19.

Evaporator conductance is defined as:

$$C_{\text{evap}} = \frac{Q}{T_{\text{evap,ave}} - T_{\text{CC,ave}}}$$

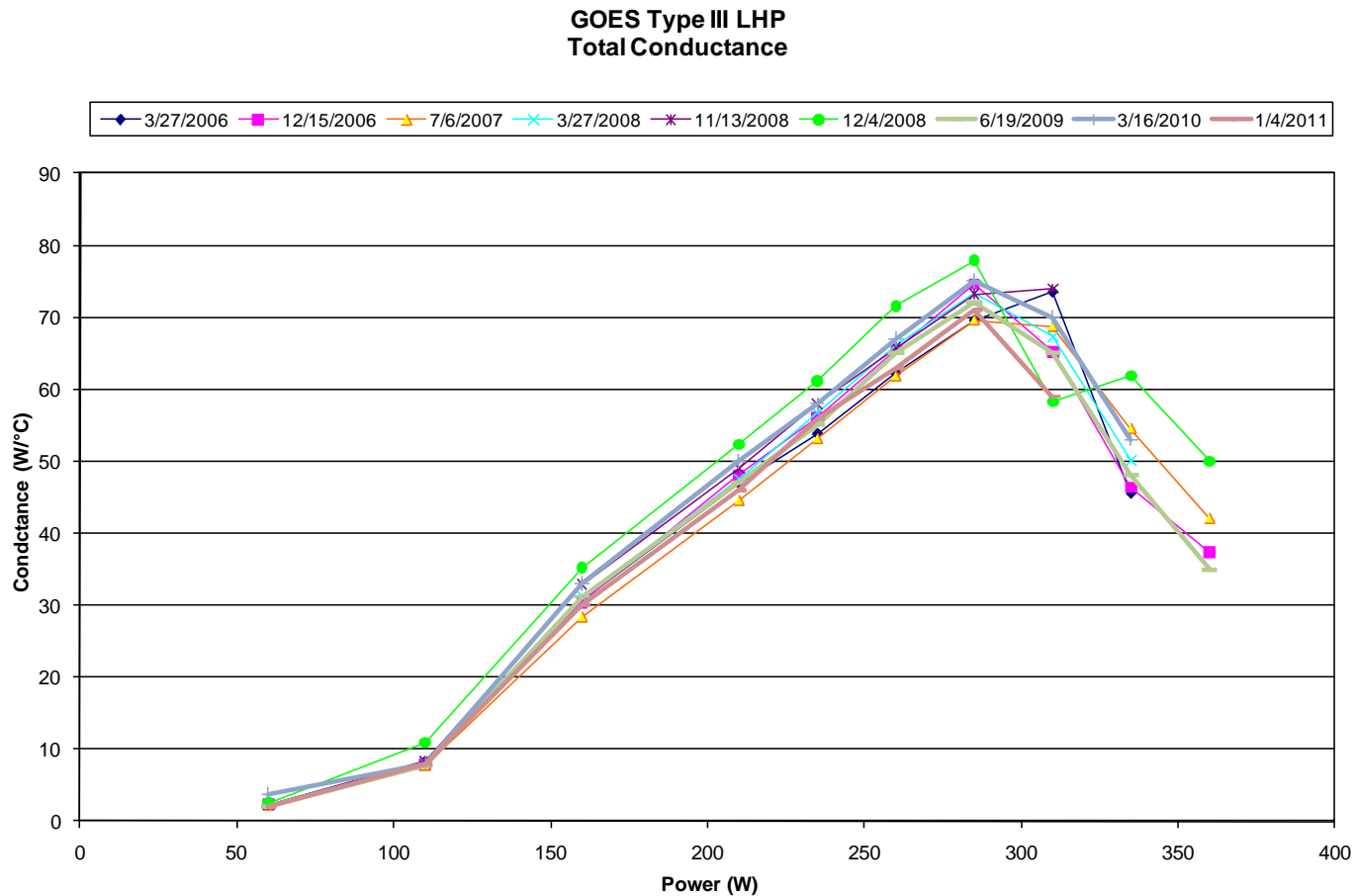
where $T_{\text{CC,ave}}$ is the average compensation chamber temperature (TCs 10-14).

Condenser conductance is defined as:

$$C_{\text{cond}} = \frac{Q}{T_{\text{CC,ave}} - T_{\text{cond,ave}}}$$

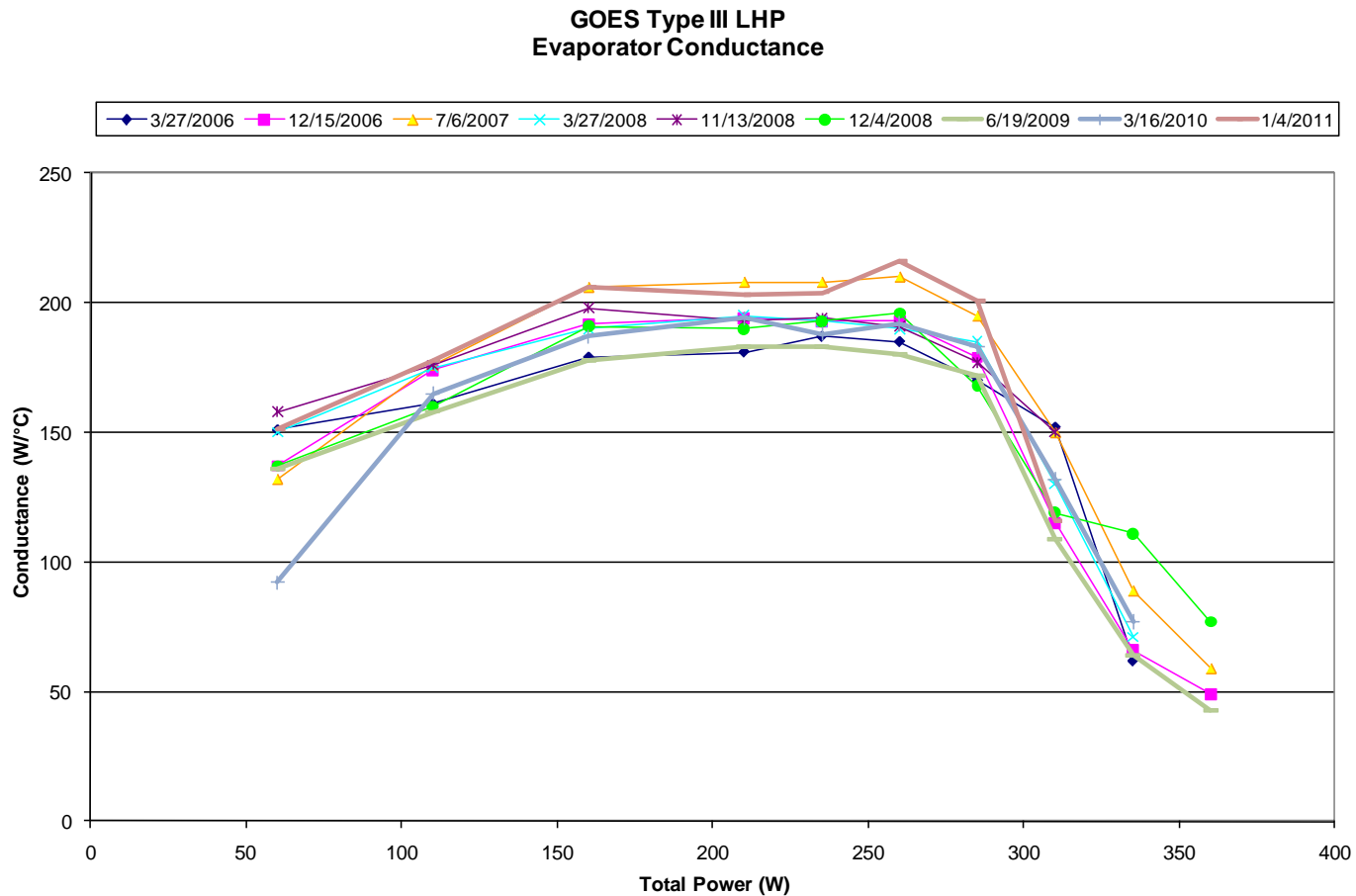
Heat Transport Limit Test

Total Conductance



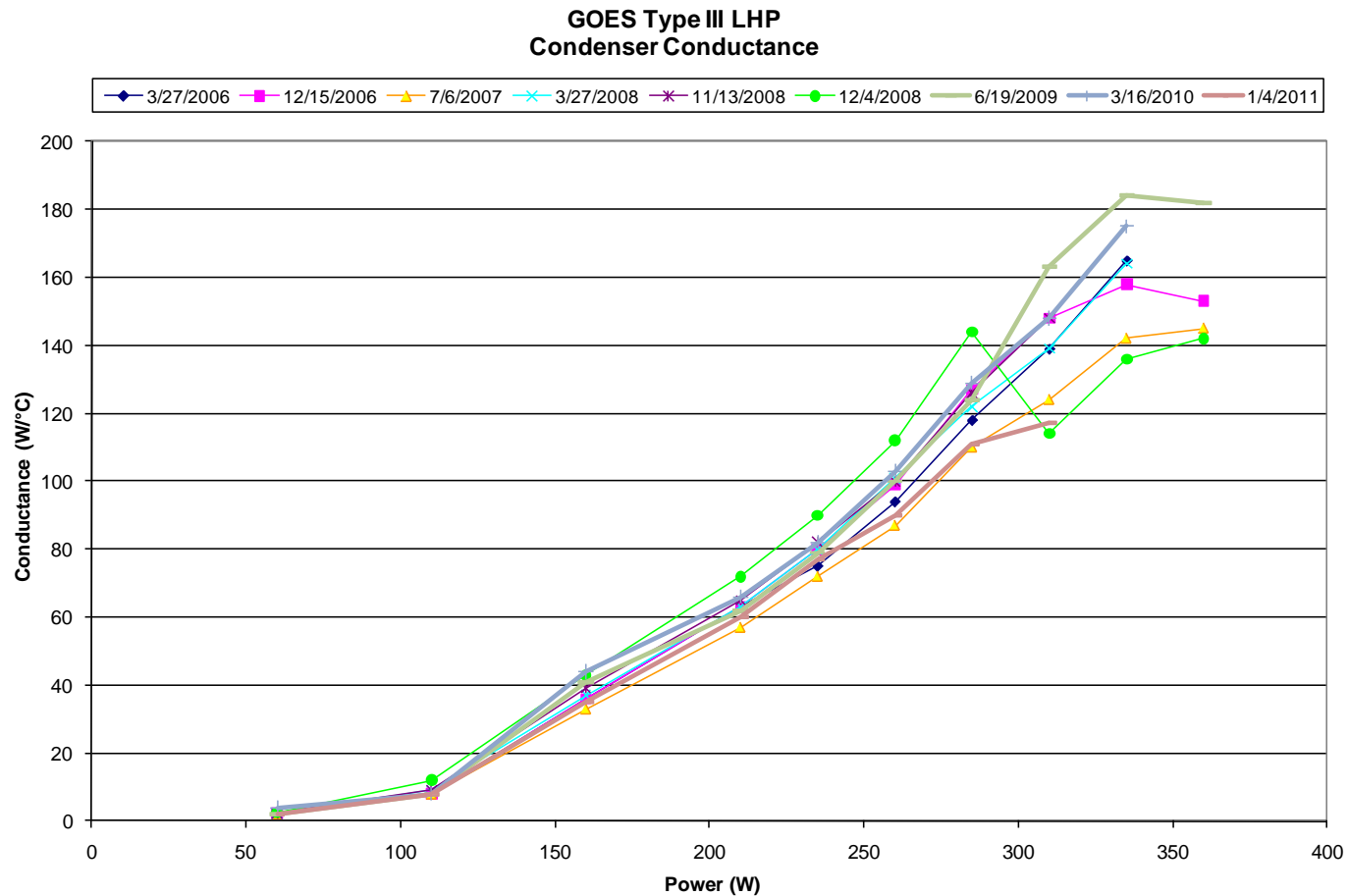
Heat Transport Limit Test

Evaporator Conductance



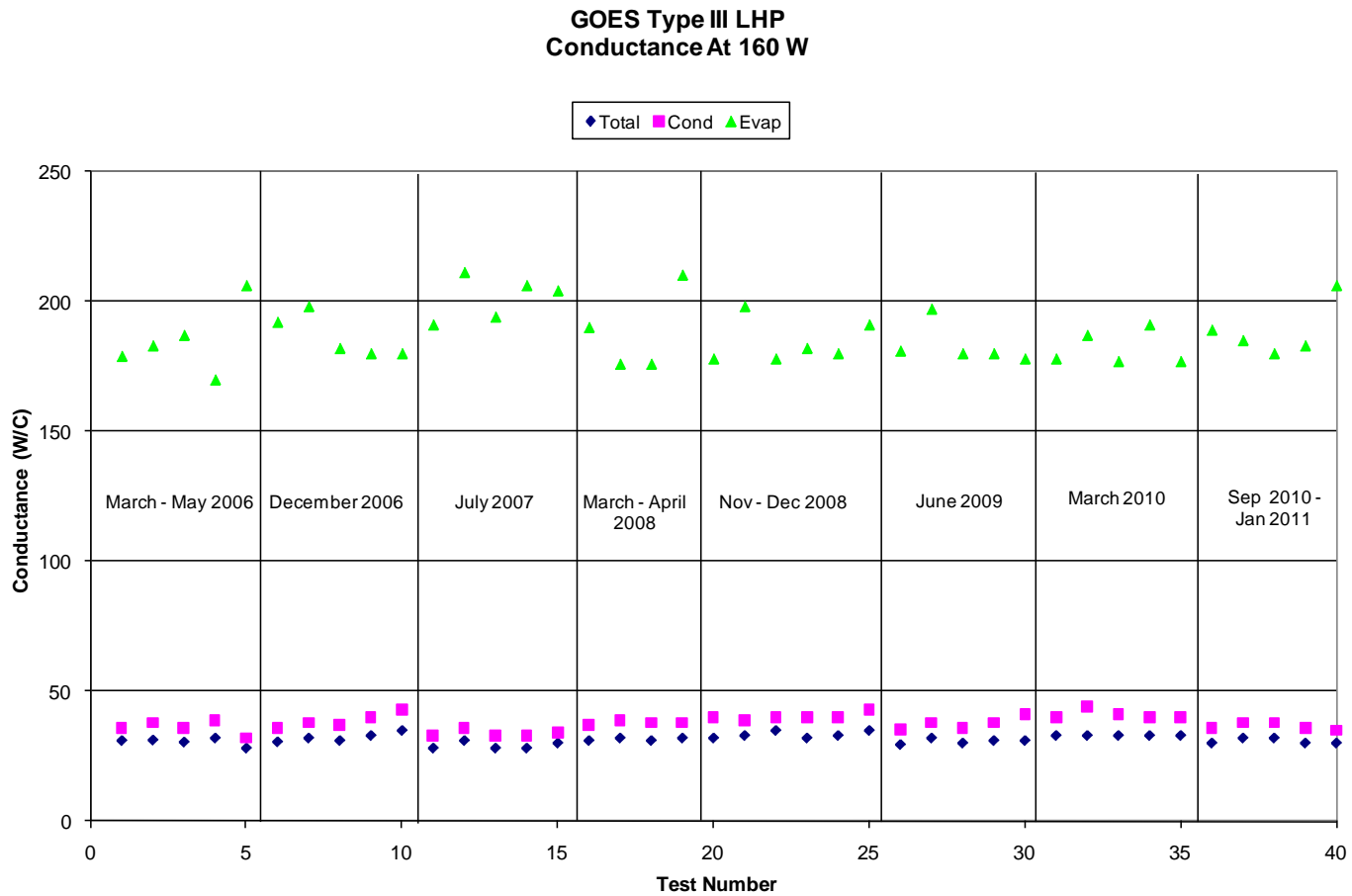
Heat Transport Limit Test

Condenser Conductance



Conductances at 160 W

(for all tests performed, in chronological order)



Conclusions

- No test anomaly seen throughout test program
- Partial dryouts during heat transport limit tests only
- No significant change in operation over time span tested
 - Due to changes in test configuration, instrumentation, and test parameters, data cannot be directly compared to data from Dynatherm or Swales tests
- LHP test set-up remains undisturbed. Additional testing will be performed if funding can be located.